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Global Climatology and Variability of Potential New Production Estimated from Remote Sensing of Sea-Surface Temperature.

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PUBLICATIONS FROM THIS PROJECT

Dugdale, R.C., D. Halpern, F.P. Wilkerson and F.P. Chavez. 1992. Remote sensing of seasonal and annual variation of equatorial new production: a model for global estimates. Advances in Space Research 14: 169-178.

Wilkerson, F.P. and R.C. Dugdale. 1995. Silicate versus nitrate limitation in the equatorial Pacific estimated from satellite derived sea-surface temperatures. In press. Advances in Space Research.

Dugdale, R.C., F.P. Wilkerson and H.J. Minas. The role of a silicate pump in driving new production. 1995. In press, Deep Sea Research.

Dugdale, R.C., C.O. Davis and F.P. Wilkerson. Uisng remotely-sensed sea-surface temperatures to estimate new production at Point Conception, california. In review Journal of Geophysical Research.

PRESENTATIONS AND ABSTRACTS FROM THIS PROJECT

1992

Remote sensing of seasonal and annual variation of equatorial new production: a model for global estimates. Committee on Space Research Symposium, World Space Congress. September.

Importance of a silicate pump in coastal regions, Universite de Marseille, Luminy, France. November. Invited seminar.

New production in the equatorial Pacific in El Niño and La Niña conditions. AGU, San Francisco, CA.. December.

1993

Upwelling, new production and the exchange of CO_2 between atmosphere and the ocean, UCLA. February. Invited seminar.

The role of silicate in global new production: a neglected nutrient. The Oceanography Society Meeting, Seattle, WA. April.

1994

The biological silicate pump: effects on new production. ASLO AGU Ocean Sciences Meeting, San Diego, CA, February.

Organizer and Chair of special session on silicate limitation in the Sea. Feb. 1994

Can silicate versus nitrate limitation be evaluated from remotely sensed sea-surface temperature? ASLO AGU Ocean Sciences Meeting, San Diego, CA, February.

Biological consequences of the 1992-3 El Nino, AAAS , June 1994. Invited

Delineation of high nitrate, low silicate, low chlorophyll in offshore upwelled waters using satellite derived sea-surface temperatures, COSPAR (Committee on Space Research, Hamburg, July, Scientific Organizer and Invited Paper.

Remote sensing and new production, Institute of Marine Biology, Crete, Geece, Invited.

ACCOMPLISHMENTS

Obtained nutrient (nitrate and silicate) regressions for a number of coastal upwelling areas and the eastern equatorial upwelling area, for both normal and El Niño conditions. (Table 1)

Calculated and compared nitrate versus temperature regressions for different sectors and sampling times in the equatorial Pacific (Table 2).

Used remotely sensed sea surface temperature (weekly averaged MCSST data) to estimate surface nitrate and silicate from 15°N to 15°S, 180°W to 90°and calculate the ratio of nitrate:silicate (Figs. 1, 2, 5).

Constructed zonal and meridional sections of nutrients across the equatorial Pacific and created surface maps to evaluate spatial variability.

Produced time sequences of pseudocolor images of nitrate, silicate and nitrate:silicate ratios for 1986-1988 that illustrated the intra and interannual variability (temporal variability) in nutrients and identify the limiting nutrient (eg. Fig. 3) .

Predicted areal new production values from remotely sensed SST for the equatorial Pacific that compare well with shipboard measured data (Fig. 4., Table 3).

Predicted areal new production values from remotely sensed SST for the coastal upwelling area, Point Conception, CA that compared well with shipboard measured data.

DETAILED SUMMARY OF PROJECT RESULTS

During this project we have collected numerous shipboard data-bases of oceanic nitrate and silicate versus temperature for both equatorial and coastal upwelling regions. These cruises all have accompanying ^{15}N measurements of new production. The inverse relationships between nutrients and temperatures have been determined and are being used to obtain surface nutrient fields from sea surface temperatures measured remotely by satellite borne sensors- i.e. AVHRR data from NOAA satellites contained in the MCSST data set for the world ocean provided by the University of Miami. The images and data derived from space in this way show the strong seasonal fluctuations and interannual El Nino fluctuations of the nitrate field. The nitrate data has been used to make estimates of new production for the equatorial Pacific which are compared with shipboard measurements when available. The importance of silicate as a nutrient driving new production and the ratio of nitrate to silicate has been discovered to be crucial to better understand the causes of new production variability, so we have added these parameters to our study and have begun to make estimates of these for the equatorial Pacific, derived from the weekly averaged SSTs.

<u>Equatorial Pacific Upwelling</u>

Nitrate regessions for 1986 and 1989 showed high r^2 and similar slopes for the 2 years of shipboard data available (1986 and 1988), although the intercept values were lower in most cases in 1988 compared with 1986 (Table 2). The statistical functions (analysis of variance type) needed to compare the slopes and intercepts are being programmed. The 1986 regressions were used to identify pixels with measurable nitrate and make some preliminary estimates of new production from space for the region 15°N to 15°S, 180°W to 90° (Table 3). The mean values for each year show the low values of the 1987 El Niño compared to the higher values in 1988. The estimates compare well with the measured values of Chavez and Barber (1987). We have recalculated their data using percent new production, f=0.14 (from data rather than apply their original model derived value of f=0.44 (Eppley and Peterson, 1979). When this recalculation is made our estimates and mean value for the 4 years, 3.03×10^{14} g C y^{-1}, compare well with the Barber and Chavez (1987) estimate of 2.7×10^{14} g C y^{-1}. Some of these data along with images and sections of surface nitrate obtained from AVHRR- SST along 150° and 110°W, during April and September 1987 and 1988, were presented by R.C. Dugdale at the World Space Congress in Washington D.C. (August 1992) published in Advances in Space Research.

We have also begun to consider the importance of another macronutrient silicate in limiting ocean productivity, in particular its impact on diatom growth. Our emphasis has to be to combine the nitrate and silicate dynamics to determine the limiting nutrient using a simulation model in which productivity is driven by diatoms that are grazed and nitrogen is recycled, unlike silicate which is lost to the deep water. The involvement for this project of this latest development has been to construct silicate/temperature relationships in addition to those for nitrate and calculate nitrate to silicate concentrations and the ratios of nitrate:silicate from SST. Such data (obtained on large spatial scale by satellite) offers new ways to evaluate limiting nutrients and compare export production in terms of silicate (ie. new production that is lost) for comparison with the nitrate derived estimates of new production. Silicate/temperature regressions are not linear inverse relationships as for nitrate but are more hyperbolic. These regressions (like those for nitrate) vary with latitudinal sector. They have been used to plot false color images of weekly averaged surface silicate distributions (Fig. 3). Using this data and the nitrate data (Fig 3), the ratio of nitrate:silicate for each pixel can be determined (Fig. 3). Red, pink and brown indicate ratios greater than 1. This ratio has been used in the past to identify nitrate versus silicate limitation and from our model to evaluate the contribution of diatoms (silicate users) to the productivity of the area. Figure 1 shows the actual values of surface nitrate and silicate and Fig 2, the ratio of nitrate:silicate along the equator (mean of 3 pixels). The ratio is below 1 (from pixel 0 to 128 (ie 180 eastward) and above 1 to the further east of the box from pixel 128 to 512, suggesting that off the shelf and westward from South America silicate may be limiting and diatoms are likely to be important players in production.

Coastal Upwelling Areas

In addition we have begun to analyze nutrient/temperature data from coastal upwelling ecosystems. Table 1 shows the regressions available for a number of data sets. These data sets all have accompanying ^{15}N measurements that will later be used to validate new production estimates that we make from the data. The data sets assimilated to date include the upwelling center off 15°S, Peru (from WECOMA 77 cruise in 1977 and from the PACIPROD cruise in 1986), the Galapagos region and the HNLC (high nutrient, low productivity) region between Peru and the Galapagos (PACIPROD 1986 data), the Arabian Sea (ANTON BRUUN 4A data from 1962) and for Point Conception, California during the El Niño year 1993. The latter have been applied to AVHRR images that were obtained during this cruise and estimates of new production were made by applying the NW Africa model of Dugdale et al. (1989) and compared well with measured ^{15}N values, especially during the cruise when active upwelling was in progress (see Dugdale et al., in review JGR).

TABLE 1

Nutrient Regressions for Coastal Productivity Systems
(linear regression for nitrate, exponential regression for silicate)

Location	Cruise	Regression	r^2
Nitrate Regression			
15°S, Peru	Joint II	NO_3=59.9-2.43*T	0.31
15°S, Peru	Paciprod	NO_3=85.0-4.88*T	0.82
Peru-Galapagos HNLC section	Paciprod	NO_3=56.06-2.29*T	0.73
Galapagos Leg	Paciprod	NO_3=47.20-1.81*T	0.87
E. Galapagos	Paciprod	NO_3=48.12-1.98*T	0.97
Arabian Sea	Anton Bruun 4	NO_3=82.13-2.95*T	0.82
Point Conception, CA	OPUS 83	NO_3=88.56-6.53*T	0.86
Silicate Regression			
15°S, Peru	Joint II	$Si(OH)_4=3291^{(-34*T)}$	0.46
15°S, Peru	Paciprod	$Si(OH)_4=10460^{(-0.62*T)}$	0.7
Peru-Galapagos HNLC	Paciprod	$Si(OH)_4=600^{(-0.255*T)}$	0.87
Galapagos Leg	Paciprod	$Si(OH)_4=259^{(-0.20*T)}$	0.9
E. Galapagos	Paciprod	$Si(OH)_4=389^{(-0.22*T)}$	0.76
Arabian Sea	Anton Bruun 4A	$Si(OH)_4=303.4^{(-0.16*T)}$	0.93

TABLE 2 Nitrate versus temperature regessions for 1986 and 1988 for the equatorial Pacific (data courtesy of Dr's Barber and Chavez)

Sector	1986 Intercept	1986 Slope	1986 r^2	1988 Intercept	1988 Slope	1988 r^2
5°N-15°N	60.45	-2.03	0.92	55.47	-2.06	0.97
1°N-5°N	59.11	-2.11	0.97	53.86	-1.97	0.97
1°N-1°S	53.86	-1.86	0.97	36.92	-1.25	0.91
1°S-5°S	59.11	-2.11	0.97	51.78	-1.80	0.95
5°S-15°S	50.43	-1.84	0.87	52.25	-1.66	0.94

TABLE 3 New Production Estimated from Weekly Averaged AVHRR-derived Measurements of SST, for the Area 180°-90°W, 15°N-15°S

Year, Julian Days	10^6 tons C d^{-1} mean $\pm$sd	n	10^{14} g C y^{-1}
1986, 274-365	0.75$\pm$0.04	12	2.73
1987, 1-364	0.63$\pm$0.13	47	2.29
1988, 1-363	0.95$\pm$0.17	51	3.46
1989, 1-179	1.00$\pm$0.91	26	3.65
Chavez and Barber, 1987*			2.70

* Use C fixation value * *f*, using *f* = 0.14 correction from Dugdale et al. /11/

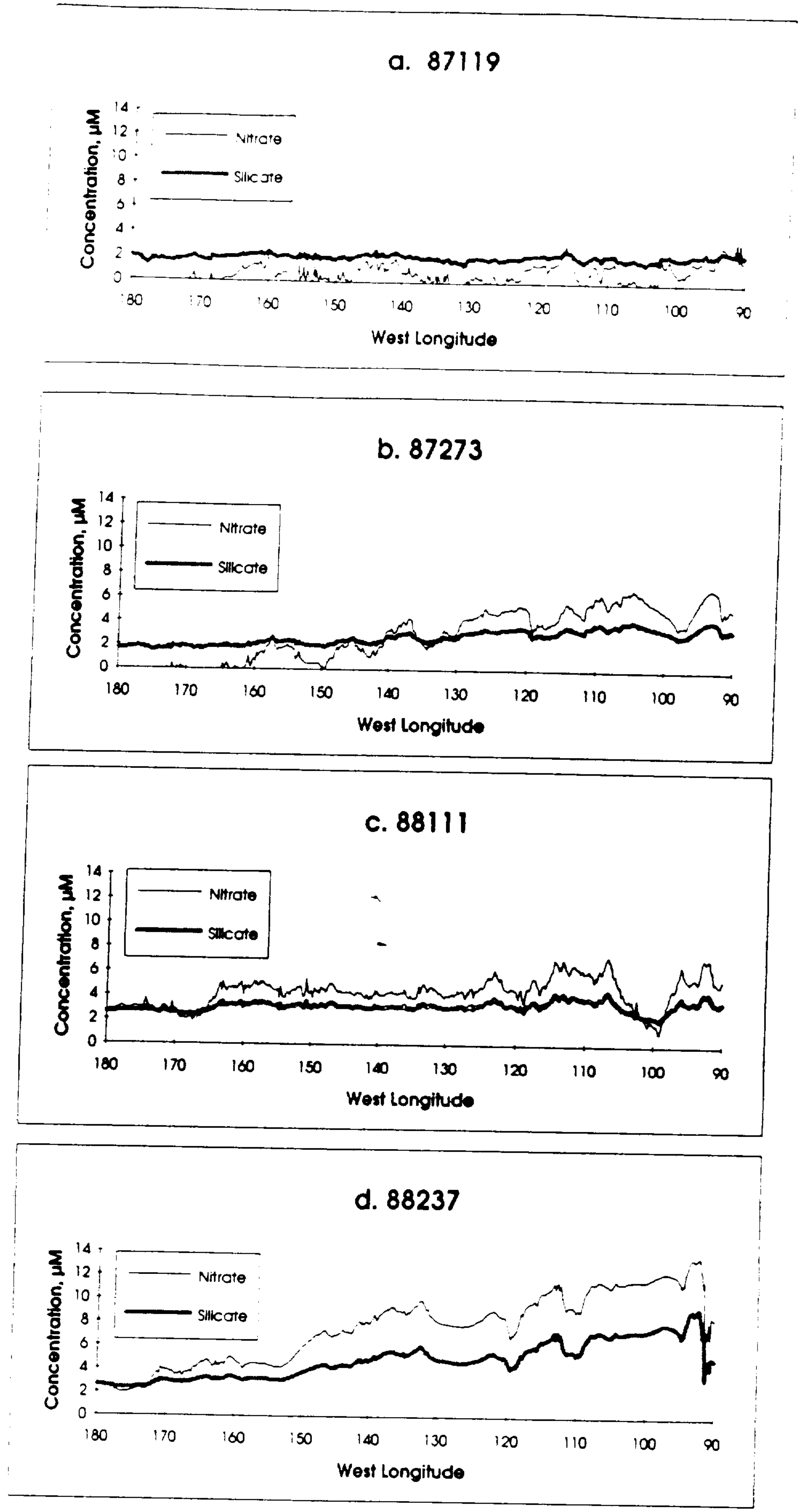

Fig. 1. Equatorial concentrations of surface nitrate and silicate (in µM) from 180°W to 90°W obtained from AVHRR-SST weekly averaged images for weeks ending the Julian Day shown.

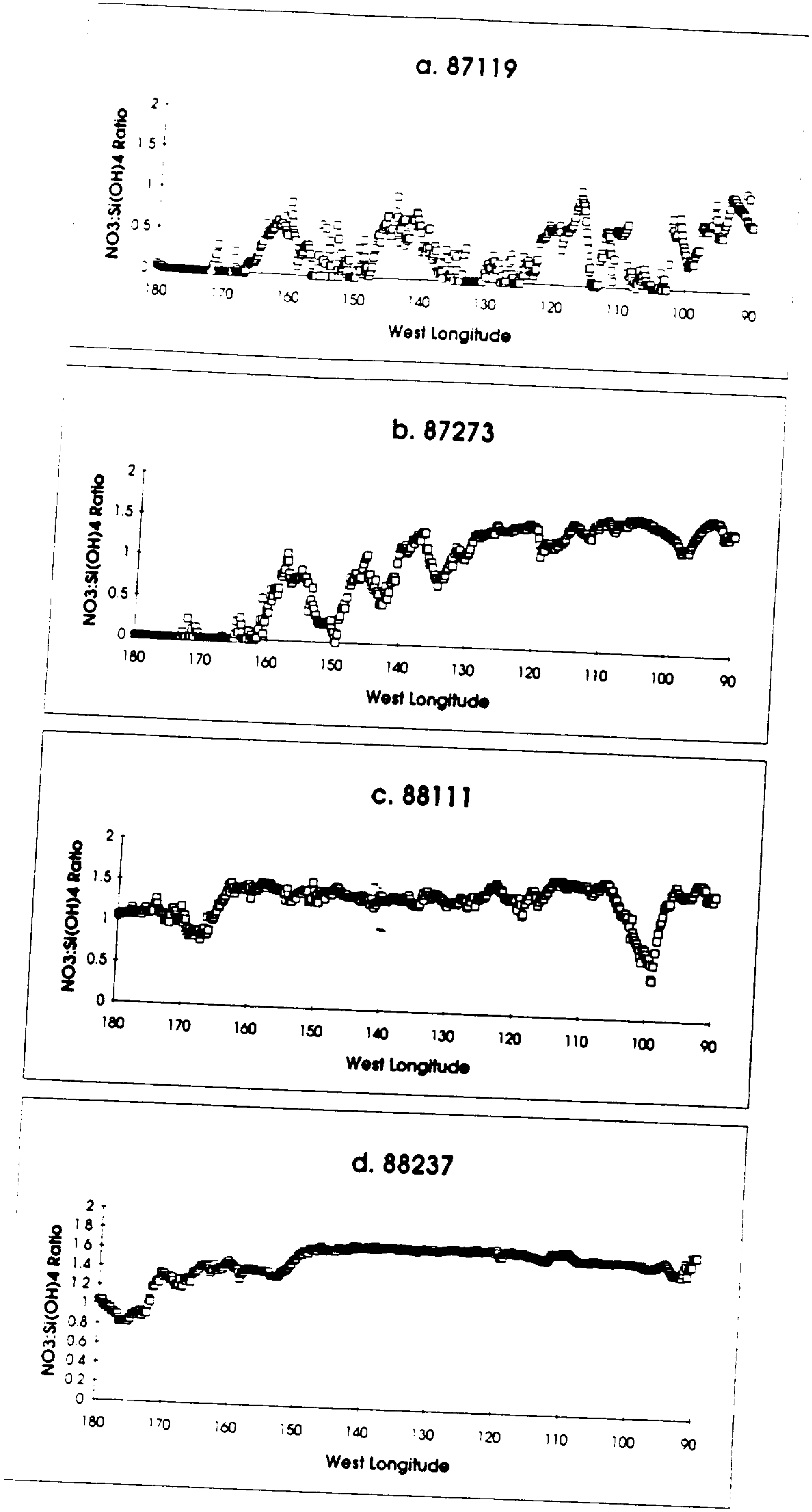

Fig. 2. Equatorial values of the NO_3:$Si(OH)_4$ ratio from 180°W to 90°W obtained from AVHRR-SST weekly averaged images for weeks ending the Julian Day shown.

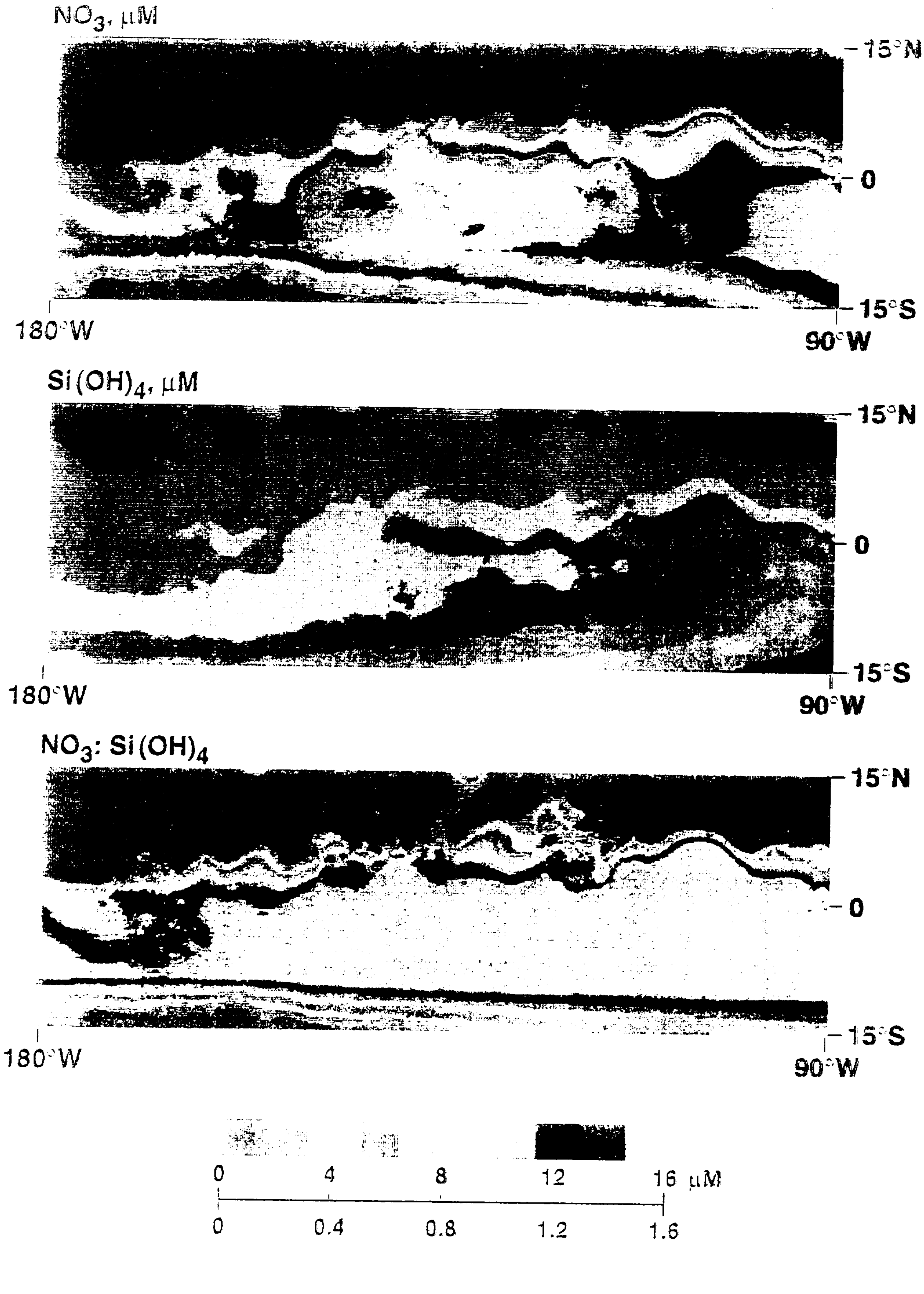

Fig. 3. Pseudocolor images of surface nitrate, silicate (in μM) and NO_3:$Si(OH)_4$ ratio from 15°N to 15°S, 180°W to 90°W obtained from AVHRR-SST weekly averaged images for week ending Julian Day 88237 (September 1988).

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REMOTE SENSING OF SEASONAL AND ANNUAL VARIATION OF EQUATORIAL NEW PRODUCTION: A MODEL FOR GLOBAL ESTIMATES

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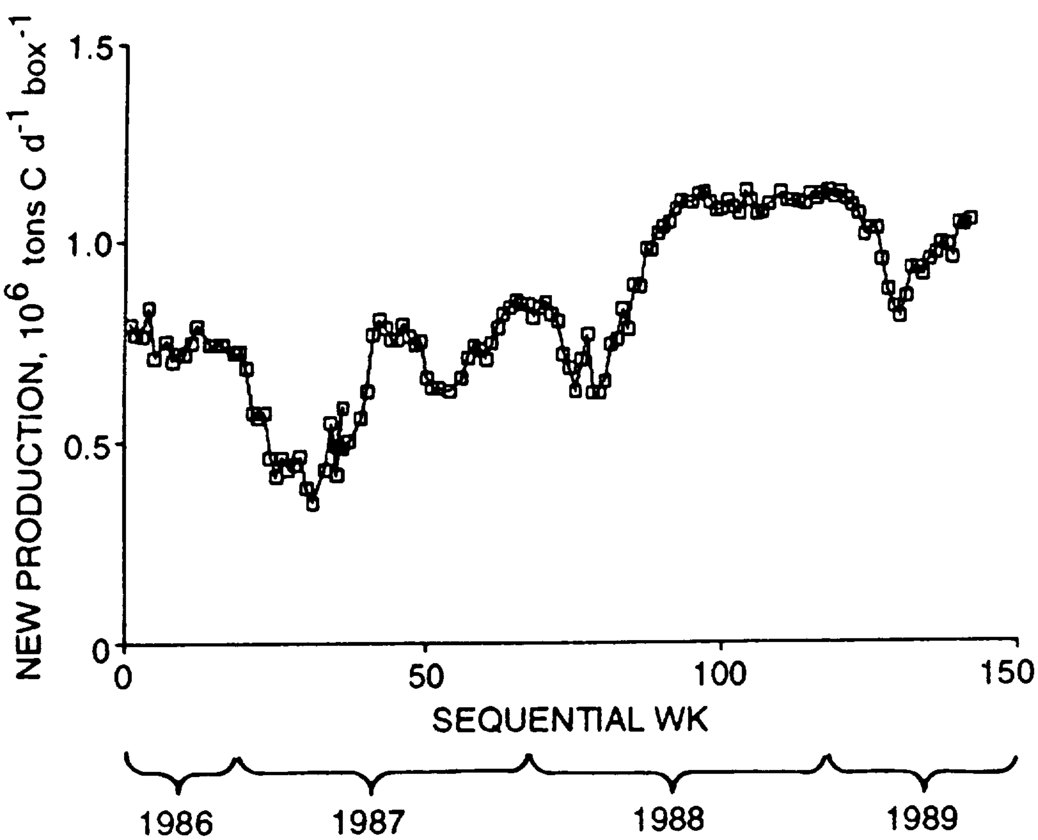

Fig. 4. Areal estimates of new production for the box 180° - 90°W, 15°N - 15°S from June 1986 to July 1989 obtained from pixels with nitrate greater than 1.5 μM derived from SST data.

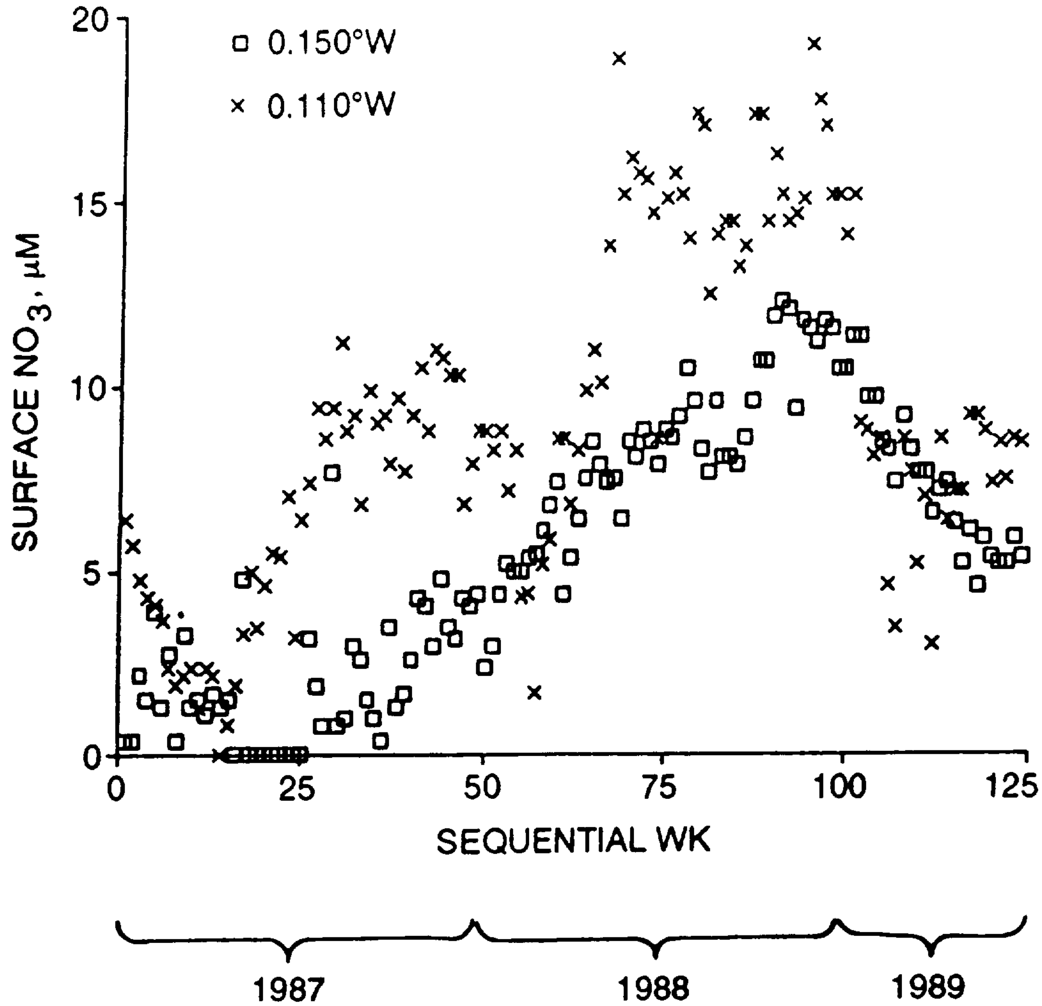

Fig. 5. Time series of surface nitrate at 0°, 150°W and 110°W from January 1987 to July 1989.